TECHNICAL PROPOSAL

EMISSION CONTROL TECHNOLOGIES
FOR OCEAN GOING VESSELS (OGVs)

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November 22, 2006

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1. Statement of Significance

Major California ports such as the Los Angeles-Long Beach ports are among the busiest in the United States, handling more than 43% of the total U.S. seaborne cargo. They are also responsible for nearly a quarter of diesel emissions in the region. Big rig trucks, diesel locomotives and mammoth container ships contribute significantly to the region air pollution and local communities are affected by these emissions. Studies over a course of 30 years (Vedal [1]) have shown significant adverse effects of ambient particulate matter (PM) on respiratory systems, especially in high risk population such as infants, young children and elderly. A recent study by Gauderman et al [2] on the effects of pollution on the children's health in Los Angeles has shown that pollution impedes lung growth in children and can cause premature death or life long health problems. Another recent study indicates more than 2500 people die every year from breathing polluted air in this region.

Ocean going vessels (OGVs) contribute significantly to the local and regional air pollution. These vessels use residual marine fuel which is one of the cheapest and highly polluting fuels. Different approaches have been proposed for reducing OGVs emissions, including cold ironing, switching to low sulfur fuel during their operation at the port complexes, water-in-fuel homogenization and emulsification (H/E) process, and exhaust gas seawater scrubbing process to name a few. Many innovations in diesel engine designs are also proposed and/or being developed. As expected, each technology has some strength as well as some limitations.

Due to its significance, large numbers of organizations from academia, government and industry are involved in research and development of diesel emission control technologies, making it a highly dynamic field. Existing technologies are constantly evolved and new technologies are being developed. It is imperative for environmental regulatory bodies such as CARB/EPA to stay abreast of these developments and have a clear concise view of various technologies available or planed, their effectiveness as well as their limitations.

2. Abstract

Under this project, we will conduct a comprehensive review of diesel emission control technologies that are deemed applicable to existing and new ocean going vessels. This review will focus on present technologies and technologies under development by maritime as well as other industries. It will encompass literature searches, other available information sources and surveys of academic, government and industry sources. The information that is compiled will include description of the technologies, their applicability to existing and new OGV's, their strengths, limitations, and corroborating data and documentations when available. The information will be evaluated for consistency and organized in a comprehensive concise manner to be communicated to ARB in the form of deliverable reports and presentations.

3. Project Objective

The objectives of this work is to

- Conduct a comprehensive survey of existing, developing, and planned technologies that are used or could be adapted and reasonably be used for control of NOx, SOx, and PM emissions from the diesel cycle propulsion and auxiliary engines of OGVs and collect and assess available performance data for these technologies.

- In consultation with ARB staff, develop a set of parameters for assessment of viability of these technologies, and evaluate these technologies for meeting target emissions and for their initial, installation and operating costs and their adaptability for the current and new OGVs.

- Submit a final report containing all of the above information.

4. Technical Plan

There have been extensive developments in methods and technologies for reducing emissions of vehicles and stationary devices in the past few decades. Three-way catalytic converters (Kummer [1]) have been used in exhaust systems to oxidize or burn the Hydrocarbons (HC) and Carbon Monoxide (CO) gases after they leave the engine. The function of a three-way catalyst depends on the combustion process. For the catalyst to work properly, the combustion process should be nearly stoichometric. If the exhaust is too lean, NOx are not destroyed and if it is too rich HC and CO are not removed. For a diesel engine, reduction of NOx is very limited due to the fact that diesel engines run lean. Thus, reduction of NOx emissions is accomplished through the design of the combustion process and/or the choice of operating conditions.

To further reduce these emissions, new methods such as exhaust gas recirculation (EGR) are being tested by diesel engine manufacturers. In the EGR approach, the exhaust gas acts as diluents in the air-fuel mixture to lower the combustion rate and temperature, increasing its efficiency and reducing NOx emissions. The maximum EGR fraction is 15-20% of the fuel-air flow rate which limits its capacity to greatly reduce emissions. Thus, multiple methods should be implemented to drastically reduce diesel exhaust emissions.

The introduction of selective catalytic reduction (SCR) systems using urea as the removing agent has shown to be effective in reducing NOx emissions in diesel engines. Urea is produced by combining ammonia and carbon dioxide at high pressure. When it is injected into the exhaust of a diesel engine, it is first hydrolyzed to produce ammonia, which reacts with the exhaust gases to produce nitrogen and water. Fable et al [2] provide a comprehensive study of the urea infrastructure required for SCR technology to meet the current and future federal emissions standards for heavy duty diesel on-road engines.

Reduction of NOx emissions can also be accomplished with a SCR system with hydrocarbons as the reducing agent. The system can use the on-board fuel tank as its reservoir and a control system to time the injection process to the engine timing to optimize the NOx

reduction process. Sumiya et al [3] have shown a 30% increase in NOx conversion at a 450 degree C exhaust temperature with diesel fuel sprayed ahead of the catalyst bed.

Diesel Particulate Filter (DPF) has been used to filter out soot or particulate matter. The filter usually contains two chambers, one for the oxidation of NO to NO2 using a platinum catalyst, and a second chamber with a ceramic filter where NO2 reacts with the particulates to "burn them off," converting them to carbon dioxide and carbon monoxide gases and inorganic dusts. The DPF is capable of trapping diesel particles as small as 2.5 microns in diameter.

Other processes used for controlling diesel emissions (NOx, PM, and SOx) are water-in-fuel homogenization and emulsification (H/E) process and exhaust gas seawater scrubbing process. These processes have significant applications for reducing emissions from heavy fuel oil (HFO) of OGVs. The water-in-HFO H/E system homogenizes and emulsifies the water and HFO before it is burned in the engine. Homogenization physically reduces the size of long chain hydrocarbons and evenly disperses them in the HFO. Adding water to this process results in the production of 5-10 micron droplets of water around and within the HFO. These droplets generate additional atomization and temperature gradients during the combustion, resulting in a more uniform combustion process and lower peak temperature.

The seawater scrubbing of the exhaust gas, removes sulfur oxides (SOx) and PM by flowing the engine exhaust gases through a seawater scrubber installed in the engine exhaust system. When the seawater is sprayed into the exhaust, the scrubbing action removes the PM and the interactions of sodium and calcium compounds remove the sulfur oxides. The estimated reductions in diesel engine SOx, PM and NOx are 85%, 50% and 3% respectively. Solids removed during the clean –up process for the scrubbing water are collected in a sludge storage tank for disposal ashore.

These technologies are for applications with existing engine design. New and innovative diesel engine designs are also being developed and tested by many research laboratories worldwide. A general survey of these developments will also be included in the study.

5. Detailed Work Plan

The study will be conducted based on generally accepted scientific research standards. Sources for information on technologies of interest can be divided into following four broad categories

1- Scientific journals and academic research centers and laboratories. Some examples are: Annual review of energy, SAE journal, University of Wisconsin-Madison Diesel Emissions Reduction Consortium (DERC), MIT Plasma Science and Fusion Center, Argonne Transportation , Combustion Engine Research Center of Swedish National Board for Industrial and Technical Development (NUTEK), and Magdeburg University in Germany (http://www.uni-magdeburg.de/ims/km/) to name a few.

2- Regulatory and government sources such as EPA, USDOT maritime administration (MARAD), United States Congress House Committee on Science and Technology,

European Commission Joint Research Center, and Canadian National Research Council and US department of Energy

3- Maritime organizations' exhibits and conference proceedings such as

- US department of Energy Diesel Engine Emissions Reduction (DEER) Conference series http://www.dieselnet.com/links/control_.html
- The Society of Naval Architects & Marine Engineering (SNAME) technology conferences and expositions.
- The Society of Automotive Engineers (SAE International) annual conferences and proceedings.
- Pacific Maritime Conferences and proceedings
- International Maritime Conferences and Proceedings

4- Industry

- Diesel Engine Manufacturers such as Caterpillar, Yanmar, Cummins, Detroit Diesel, Marine Diesel Engine
- Engineering Design companies such as FEV (http://www.fev.com/) and IAV (http://www.iav.de/eng/)
- Manufacturers of diesel emissions control technology such as TABC, Johnson Matthey Catalysts
- OGVs owners such as SeaRiver marine Inc (Exxon Mobil) and International Chamber of Shipping.
- Port Operators such as Ports of Los Angeles and Long Beach

The key to a systematic and comprehensive review of these sources is to use connections to prominent leads in each of these categories and, to the extent possible, use their resources in pursuit of information. The CSULB investigative team has extensive and direct links to many sources within each group which will be approached for leads and information.

Once the potential technologies are identified, the next step will be survey and assessment of these technologies. Some guidelines for the study, including set of parameters that would serve as input to the decision as to whether a particular technology is viable will be developed in collaboration with ARB staff. Technologies identified will then be surveyed via phone, in person interviews and other appropriate means. It is imperative that review of technologies be comprehensive, data and information be collected from unbiased, and to the extent possible form independent and multiple sources. If a technology is deemed promising yet sufficient data does not exist due to proprietary nature of the technology, it will be classified as technologies to watch.

Direct validation of information and data furnished by the provider of technologies is beyond the scope of this work. However, a review of methodologies and background of such information is necessary as part of determination of viability of a technology. CSULB team will rely on technical expert members of the CEERS consisting of faculty members in Chemical, Environmental, Mechanical and Electrical engineering disciplines and other consultants when

necessary for these technical evaluations. The entire methodology and evaluation process, including evaluation parameters, sources and scope of necessary data will be developed in collaboration with ARB staff to ensure it will meet requirements.

5.1 Statement of Work (SOW)

Task 1: Survey

Task description: CSULB (the contractor) will survey available scientific, technical, marketing and other literature related to emission control technologies that are used or could reasonably be used for control of NOx, SOx and PM emissions from the diesel cycle propulsion and auxiliary engines of ocean-going vessels. The technologies will include those intended for ocean-going vessel use, and technologies from other areas (e.g., railroad and other mobile and stationary source engine emission control technologies) that could be adapted to both new and retrofits of existing ocean-going vessel use. The technologies should cover existing, evolving or planned technologies. The contractor will survey all current and potential manufacturers of such systems, via telephone, in-person interviews or other means of communication.

Task 2: Assessment:

Task description: CSULB will assess the information obtained from this survey which is to include but not be limited to: specific pollutants targeted by the technology, emission control effectiveness, durability, installation costs and requirements, shipboard size requirements, procurement cost, operating cost and requirements, installation cost, end-of-life costs and requirements, general pros & cons, cross-media effects, and any other parameters that would serve as input to the decision as to whether a particular technology is viable in a general sense and also for any specific installation. The final list of included parameters will be chosen in consultation with ARB staff.

Task 3: Final report

Task description: CSULB will write a final report discussing detailed descriptions of the principle technologies studied and the systems that use them, the literature review and survey methodologies, and the level of interest and cooperation of the parties involved. The information obtained in tasks 1 and 2 will be included in a concise format, and will be discussed in the body of the report. Key information might also include the technology approach, stage of development or commercialization, costs (both capital and operating), available scientific, technical, marketing and other literature related to emission control technologies that are used or could reasonably be used for control of NOx, SOx and PM emissions from the diesel cycle main propulsion and auxiliary engines of ocean-going vessels. Any other useful information will be included.

Additionally, the contractor will provide to ARB any other available documentation on each technology, such as technical brochures, any available test data and test reports, or any other material that can aid in characterizing the technology. The contractor will also present the results of the study at a seminar at ARB's Sacramento facility.

5.2 Deliverables are:

1. Interim progress report due quarterly during the contract period describing the status of each task, results to-date, and any obstacles and proposed solutions. Submittal of progress reports should correspond with invoice submittal.
2. Final report as described above and seminar presentation at ARB's Sacramento facility.
3. Other available documentation on each technology, such as technical brochures, any available test data and test reports, or any other material that can aid in characterizing the technology.

Milestones consist of monthly project meetings with ARB staff (teleconferences or others) to discuss progress and plans.

5.3 Staffing and work load

Emission control technology for OGV's is a fast paced project. Therefore, it requires the simultaneous involvement of several individuals in order to meet the ambitious timelines of the project. The list of staff is

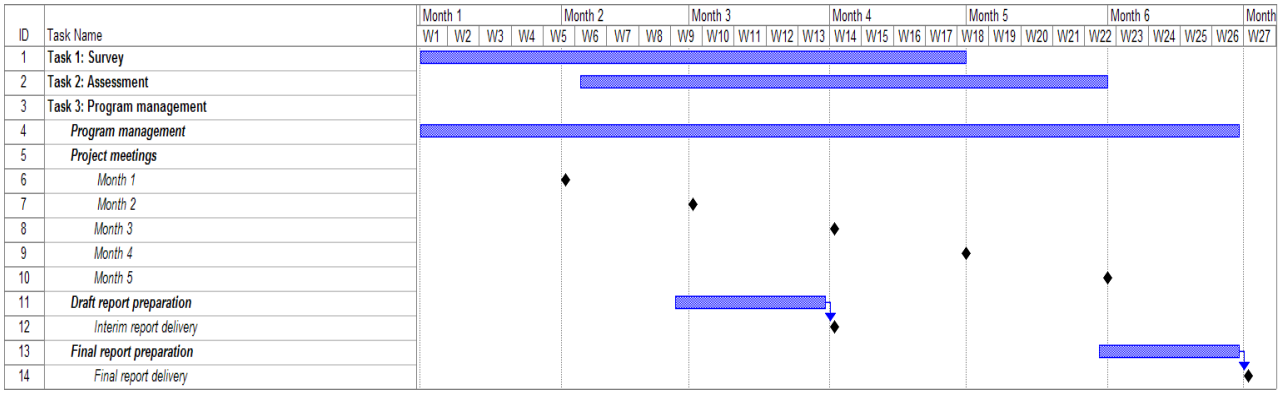
Dr. Hamid Hefazi is the principal investigator.
Dr. Hamid Rahai is the CO-PI and task manager
Ms. Asieh Jalal is a research associate
TBD, Graduate student(s) is (are) research assistant(s)
Ms. L. Tejwani, technical support

Table 1 below shows estimated numbers of hours that each staff spends on each task

Staff	Task 1	Task 2	Task 3	Total
H. Hefazi	200	30	30	260
R. Rahai	40	200	20	260
A. Jalali	120	120	20	260
Graduate Student	200	300	20	520
L. Tejwani	50	10	40	100

6. Project Schedule

The proposed period of performance is March 1, 2007 – August 31 (approximately 26 weeks). The project schedule including deliverable and milestone dates are shown below. Approximately six months will be added at the end for final report review and approval at ARB, giving a contract termination date of March 1, 2008.

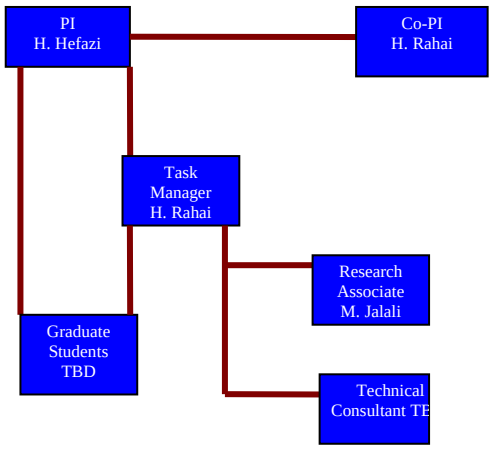


7. Program Management Plan

Dr. Hamid Hefazi, professor and Chair of Mechanical and Aerospace Engineering, will be the PI for this project. Dr. Hamid Rahai, professor of Mechanical Engineering and the director of The Center for Energy and Environmental Research and Services (CEERS) at California State University, Long Beach (CSULB) will support the project as Co-PI and task manager. The team will be supported by research associate (A. Jalali) and a graduate student (TBD). Mrs. A. Jalali has a MS degree in Chemical Engineering and is a technical staff member of CEERS. Other CEERS faculty and technical consultant may be used as appropriate.

The PI will primarily be responsible for program management and conducting the survey. This includes identifying sources, making contact and collecting the information. The CO-PI (task manager) will be responsible for processing and assessing the information. He will be assisted by the research associate. Other technical consultant will be used when necessary. The graduate student(s) will be involved in literature search, processing information and generally assisting the PI and Co-PI. The organizational chart is shown below.

Organizational Chart



7.1 Key Personnel

Dr. Hamid Hefazi (PI) is Professor and Chair of Mechanical and Aerospace Engineering department at CSULB. Professor Hefazi received his Ph.D. degree in Aerospace Engineering from the University of Southern California in 1985. He has been involved in a broad range of research activities in fluid mechanics, including geophysical fluid mechanics and computational fluid dynamics (CFD), with emphasis on the computation of transonic flows over complex geometries. His more recent works have been on the application of CFD in wind turbines and environmental issues, aerodynamic design optimization, hydrodynamics and aeroacoustics. He has more than 40 papers in various publications and is a senior member of the American Institute of Aeronautics and Astronautics and Americam Society of Mechanical Engineers (ASME). He has been the Principal Investigator for twenty (25) externally funded projects (exceeding $7.5 millions) during the last 8 years, including projects sponsored by the National Science Foundation (NSF), the Boeing Company, Northrop Grumman, Honeywell and Office of Naval research (ONR). Since year 2000, he has also been the task manager for two multi-year, multi-million dollar project on developing "fast ships" sponsored by US Transportation Command (USTRANSCOM) and US Maritime Administration (USMARDA) and Office of Naval research (ONR). He has worked as a consultant for Prada 2000 and 2003 America's Cups challenges, as well as consultant for Mariah Powers inc in the area of development of wind turbines. He is the director of Computational Research Laboratory at CSULB. Dr. Hefazi has served as director for a number of other projects in the College of Engineering, including the technology reinvestment program (TRP), Employment Training program (ETP) for Boeing and Mattel Inc. employees, and two projects sponsored by the California Trade and Commerce Agency. Dr. Hefazi is the University representative on the steering committee of the "Boeing Technology Center" located in the College of Engineering and director of the Boeing sponsored "Certificate Program in Aerospace Technology". He is also a member of the California Space Grant Consortium.

Dr. Rahai, CO-PI and Task manager has been teaching, consulting, and performing research in the area of Energy and Environment, Mixing and Turbulence and Aerodynamics since 1988. He is the coordinator of various undergraduate and graduate courses in the areas of combustion, Computational Fluid Mechanics and Heat Transfer, Inviscid and Compressible Flows, Viscous Flows, Air Conditioning and Refrigeration, Experimental Techniques in Fluid Mechanics and Heat Transfer, and Turbulence. He has been the principal investigator on projects related to: reducing emissions of natural gas combustor, reducing emissions of diesel engines, distortion of a passive scalar by two-dimensional and axsisymmetric objects; the effects of mean strain rate on decay of a temperature variance; and dissipation of a passive scalar in the presence of a mean velocity gradient. Other projects include turbulent flow in the interaction region of a wing-body junction; numerical analysis of turbulent flow past a simplified heart valve prosthesis, and development of a high efficiency vertical axis wind turbine. He is the recipient of numerous Scholarly and Creative Activities Awards, including the 2002-2003 CSULB Distinguished Faculty Scholarly and Creative Activities Award and Northrop Grumman 2004 Excellence in Teaching Award. He has authored and coauthored more than 50 scientific papers, is a member of the *American Society of Mechanical Engineers*, the *Society of Automotive Engineers*, and the *American Society of Heating, Refrigerating and Air Conditioning Engineers*. He has been a reviewer for the National Science Foundation, International Journal of Heat and Fluid flow, Journal of Applied Thermal Engineering, ASME journal of Fluids Engineering, and the AIAA Journal. Dr. Rahai has two pending patents, "Vertical

Axis Wind Turbine with Optimized Blade Profile' (with H. Hefazi), and "Efficient Selective Catalytic Reduction (ESCR) Filter" for reducing diesel engine emissions.

Other CEERS faculty members and staff which include faculty from Mechanical and Aerospace, Chemical, Civil, and Electrical Engineering Departments will be consulted as necessary. CEERS statement of objectives and information about key faculty members are provided in the appendix.

Curricula Vitae of key personnel are attached.

8. Related Research

The Center for Energy and Environmental Research and Services (CEERS) is a multi-disciplinary research center housed in the Department of Mechanical and Aerospace Engineering in the College of Engineering at CSULB and is dedicated to research and development in the areas of energy and environment. Since its establishment in fall 2003, the center has successfully conducted research and development projects in the areas of renewable energy, diesel emission reductions, water resource management, pollution assessment and mitigation, among others. CEERS has a very active advisory board consists of members from academic, government and industry which meet on bi-annual basis and provide significant guidelines and supports toward its mission and activities. CEERS faculty have had two patent applications in the area of renewable energy and diesel emission reductions in recent years and with the level of expertise and activities and the full support of the university, they expect to continue to make significant contributions at local, state, national and international levels in the field of energy and environment. The statement of objective of the CEERS is given in the appendix.

Some specific past or on-going relevant research projects in the center include:

- Development of an exposure model for diesel locomotive emissions near the Alameda corridor
- Reducing Diesel Emissions of Ocean Going, Proposal submitted (under review) to the Port of Los Angles, 2006-2007 Port Air Quality Mitigation Incentive Program (PAQMIP) in partnership with Seaworthy Systems, Inc., SeaRiver Maritime, Inc. and Marine Exhaust Solutions, Inc.
- Reducing diesel NOx and PM emissions of diesel buses and trucks
- The effects of coil inserts on NOx emission of atmospheric gas burners
- Mixing enhancement of a wall jet with tabs
- Investigation of near field characteristics and effectiveness of ring injectors for injecting hydrocarbons into the diesel engine exhaust for reducing diesel emissions.
- Near-field investigations of two side-by-side turbulent jets with various momentum ratios in a cross flow
- Development of guide-vane enclosures for a high efficiency vertical axis wind turbine for freeway and highway applications